# Long-term management of contaminated freshwater bodies and catchments. Decision making exercise with the MOIRA system

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## INTRODUCTION

In the mid-long-term after a nuclear accident, the contamination of drinking water sources, fish and other aquatic foodstuffs, irrigation supplies and people's exposure during recreational activities may create considerable public concern, even though dose assessment may in certain situations indicate lesser importance than for other sources, as clearly experienced in the aftermath of major accidents, like Chernobyl. For such a problem, definition of appropriate remediation strategies and wide stakeholder involvement are crucial to guarantee the acceptability of the implemented management solutions. The MOIRA system was developed during the IV Euratom Framework Research Programme (EFRP) and tested and compared with other models inside the EVANET-HYDRA network of the V EFRP. It was designed to allow for a reliable assessment of possible alternative management strategies, including an objective evaluation of their economic, social and ecological impacts in a rational and comprehensive manner. MOIRA considers countermeasures effectiveness and a full scope decision analysis methodology, making use of multi-attribute analysis (MAA), which can take into account the preferences and the needs of different types of stakeholders in cases of higher complexity.

This work presents and discusses the main conclusions derived from a decision-making exercise regarding such problems in which MOIRA has been be used as a decision support tool. The exercise was organised in the frame of the Nuclear Safety Council (CSN) Annual Exercises and Simulations Program 2007 and within the EURANOS Project of the 6$^{th}$ EFRP. It has featured the participation of the organizations responsible for emergency management and the affected services, as well as local and regional stakeholders and several international observers (see Table 1).

## OBJECTIVES

The main objective of the demonstration activity has been to test the applicability of the MOIRA system for the definition and analysis of a variety of appropriate strategies for the long-term management of contaminated freshwater bodies, for both lakes (local scale) and rivers (regional scale), as well as the validity of the system as a tool in the decision making process able to incorporate inputs from different ranges of stakeholders.

A complementary objective was to have the MOIRA system fully operative in an operational emergency response centre, getting useful feedback from operators and users.

**Table 1.** Stakeholders and observers participating in the exercise

| Stakeholders involved in the exercise | Observers invited to attend the exercise |
|---|---|
| • CSN authorities: Staff from Emergencies and Radiological Protection of the Public departments.<br>• Ministry of Environment: General Commissary of the Tagus Water Administration Authority and technical advisors.<br>• Ministry of Interior: Civil Protection and Guardia Civil representatives<br>• Autonomous Government of the region: Regional Government of Extremadura: Counsellor of Environment and technical advisors.<br>• Central Government representatives: Sub-delegation of the Government in Extremadura region representatives (decision-makers in nuclear emergencies).<br>• Water Management Company: Canal de Isabel II representative (water supply for human consumption in Caceres city, public company). | • University of Extremadura and University of the Basque Country: Scientist advisors on determination of environmental radioactivity and its effects.<br>• Ciemat: Staff from the Unit on Research on Radiological Protection of the Public.<br>• Ministry of Defence: Military Unit of Emergencies representative.<br>• ENRESA (National Radioactive Waste Management Company) representative.<br>• International observers:<br>– NRPA (Norway),<br>– RPII (Ireland),<br>– IA-NUTEM (Portugal),<br>– NIPNE (Romania),<br>– ENEA (Italy). |

## SCENARIOS ANALYSED

The exercise was focused in the mid and long-term radiological consequences, as well as in the different alternatives to manage the post-emergency situation in the water contamination-affected area. The endpoints were the radiological recommendations to be given to the authorities in charge of water supply in the contaminated zone, and the decision-making on their side.

A simulation of the contamination resulting from a severe accident leading to significant releases of $^{137}Cs$ and $^{90}Sr$ (3% and 0.6% of the reactor inventory respectively) was performed with the RODOS system, and the resulting map of contamination was transferred to the MOIRA system. Two specific scenarios in the contaminated area were analysed:

- The first was focused on the contamination of a group of small lakes (local scale). In this scenario, the individual dose for the most exposed individuals was the main concern, with local fishermen being the critical group.
- The second looked at a river basin contamination (regional scale). Usually, these scenarios lead to a reduced individual dose, but affect very large populations, and thus the collective dose may be high. For the exercise, the contamination of part of the Tagus river basin was considered. The purpose was to show MOIRA's suitability to study the problem of dragged contamination due to run-off in the river water, thus reaching river sections not directly contaminated by fallout from the radioactive cloud. Due to this contamination drag, which may last for many years, usage of water or fish intake in places far from the accident could constitute an exposure pathway of the population, so there is a need to evaluate the scale of the problem and the feasibility of countermeasures aimed at reducing the dose to population.

Previously to the exercise, a full customisation of the different MOIRA data sets and GIS thematic maps was performed to guarantee the representativeness of the details with regard to land and water uses. The morphological characteristics of lakes and rivers of the region were incorporated. The estimations of run-off and withdrawal from rivers reproduce the mean hydrological behaviour based on historical records (about 30 years) with good accuracy.

## RESULTS AND DISCUSSION

### Small lakes scenario

In the case of the small lakes, fish ingestion was considered the main concern. The lakes are in an environmentally protected area, and water is not used neither to irrigate crops nor for human consumption. Recreational fishing is the main activity that could lead to significant human exposure. Concentrations of both $^{137}Cs$ and $^{90}Sr$ in water get down quickly. However, the contamination levels in fish and sediments remain rather high for many years. Even after 30 years, fish contamination was of the order of 3000 Bq/kg of $^{137}Cs$ for prey fish and 10000 Bq/kg for predators. The dose to a critical individual was assessed to be well above 1 mSv/y (5.6 mSv in the first year; 45.3 mSv/y in 30 years). Thus, some action was warranted.

MOIRA was used to simulate the effect on fish contamination and dose reduction of different chemical countermeasures (potassium addition, lake and catchment liming, fertilization). None of them was able to significantly improve the situation due to the short water retention time. This is in agreement with actual experience. A physical removal of the lake sediments was more effective to reduce fish contamination and doses. It achieved a reduction in contamination and doses of about 60%, but there were several drawbacks associated, the high assessed costs (of the order of 3M€) being not the less important. Finally, the consensus was obtained on the need of implementing a fishing ban or a fish ingestion ban in the area as the only efficient measure. Obviously, the practical perspectives of that option were discussed during the exercise by the relevant regional authorities who should be responsible for its implementation.

### River scenario

This part of the exercise was focused in several sectors of the Tagus River downstream from the fallout affected zone to the Portugal border. This is a regulated chain of hyper-annual reservoirs with different uses depending on the sector. Water is used for crop irrigation in well defined areas, supply of drinking water to towns and cities (the main being the city of Cáceres, with about 80,000 inhabitants) and recreational use due to the existence of a natural park in the region. The affected amount of crops, water, and livestock products is a paramount factor in the assessment of collective doses. A summary of the radiological importance of the situation is presented in Fig. 1. Collective dose by crop ingestion is in general very modest due to the characteristics of the agricultural production of the region, with a high percent of the irrigated land devoted to tobacco and forage and low area to crops intended for direct human consumption. Thus, the dominating pathways are, depending on the river sector, the ingestion of fish (which are contaminated with a few kBq/kg, depending on the season), the external exposure to sediments, the ingestion of livestock products and water.

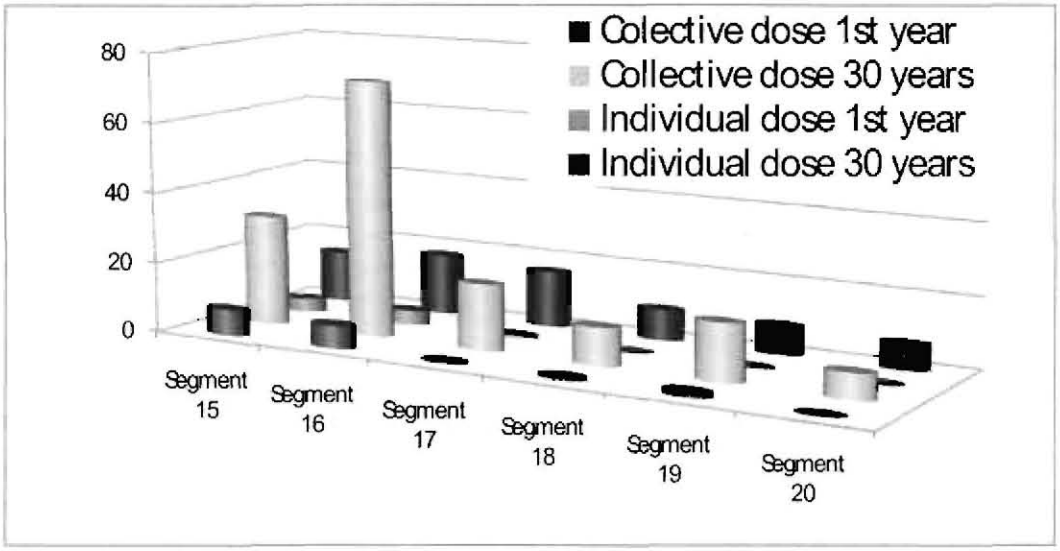


**Figure 1.** Collective and individual effective dose assessed for the first year and the 30 year period at different river segments downstream of the directly contaminated area.

Water contamination showed a strong seasonal dependency, because in the dry season (May to October) precipitation is very scarce, thus also reducing the runoff of radionuclides from the catchment to the water. The cleanup effect by water coming from upper segments of the river also dilutes the contamination in the water. This effect is more pronounced in the case of Sr-90, due to the non-linearity of its behaviour with respect to runoff intensity. Contamination of sediments implies a reload of contaminants in water in the long-term. It increases continuously, even after 30 years, for $^{137}$Cs-137 while, for $^{90}$Sr, remains almost stable. These effects are depending on the characteristics of each reservoir.

Management alternatives were discussed with the participants at the exercise: fish ingestion ban, treatment of drinking water and sediment removal could indeed be effective at reducing doses or contamination. However, the feasibility of the latter in a large reservoir was, according to the water management authority, very doubtful.

In any case, the MOIRA system allowed the stakeholders to get a very close idea of the magnitude of the expected problem. Both observers and stakeholders agreed that MOIRA proved to be a helpful tool for decision making in kind of scenarios. The exercise also unveiled the need of a better interface and understanding between the stakeholders.

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